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ELECTRODYNAMICS OF THE HIGH LATITUDE IONOSPHERE

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A broad range of scientific investigations ranging from the development of large scale models of ionospheric convection to small scale plasma flows associated with polar cap arcs is described. It is shown that during times of northward IMF, coherent mesoscale convection features can frequently be identified at high latitudes. We now have the ability to quite accurately reproduce the convective features of the plasma at high latitudes during periods of southward IMF.

Advances in our understanding of electric field coupling in plasma structures and the differences in local and height integrated Joule heating rates are also described. The importance of the bottomside F-region concentration in determining the effectiveness of electrical coupling is emphasized.

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ELECTRODYNAMICS OF THE HIGH LATITUDE IONOSPHERE

Introduction

During the past research period we have pursued the study of ionospheric dynamics and plasma structure at high latitudes. This research has been devoted to the study of the electrodynamics of polar cap arcs that appear during periods of northward IMF and to the charaterization of the bulk transport properties of the plasma during periods of southward IMF. In addition we have begun the developement of computer software to allow a rigorous examination of the plasma and electric field structure that exists at high latitudes. Below we briefly describe the progress in each of thes areas that has been made during this research period.

Polar Cap Arcs

Ground-based observations of discrete auroral forms in the polar cap have been undertaken by the AFGL group for many years. They have established their existence during times of weakly southward and northward IMF and their coherence over spatial scales of 100 to 1000 km and temporal scales of many hours. During this years activity we have undertaken an extensive data reductiona nd anlysis coampaign to establish the convective properties of the plasma associated with these sub-visual, sun-aligned, polar cap arcs. We have concentrated on a time period during which all-sky image intensified pictures were taken during over passes of the DE-2 satellite at Thule, Greenland. This combination of data allows us to establish the temporal and spatial coherence of the features and to

use this information to extrapolate to two dimensions, the data taken in a one dimensional slice by the DE-2 satellite. We have been able to show that the sun-aligned arcs, accurately track gradients in the convective motion of the plasma. Sometimes these gradients are associated with a reversal in the ion flow from sunward to antisunward, but at other times they may simply be embedded in a region of sunward flowing plasma. In both cases the flow with respect to the arc is predominantly along the arc and reverses direction across the arc. Thus in circumstances where a reversal in the flow is seen, the polar cap arcs either designate narrow isolated convection cells or they indicate a bifircation of a larger convective cell into "finger like" distortions. Figure 1 shows an example of the convective flow implied by the combined data sets that have been examined in detail by Carlson et al. [1988]. An abstract of this work published in the Jounal of Geophysical research is enclosed in this report.

High Latitude Joule Heating

Joule heating is important to both the ionized and neutral constituents of the atmosphere. Enhanced ion temperatures resulting from this process change the distribution and composition of the ionospheric plasma, thus affecting the total electron content and the processes generating plasma structure. Heating of the neutral atmosphere affects the neutral gas scale-height and thus the frictional forces experienced by orbiting spacecraft. During this research period we have undertaken a study of the Joule heating rate at high latitudes, the factors affecting its magnitude and the limitations of a single data set to accurately determine the magnitude of this parameter. We have found dramatic differences between the local joule heating rate observed by a satellite near 400 km and the height integrated joule heating rate determined from measurements taken at this altitude. The former parameter is weighted by the local ion concentration while the latter is weighted by the height integrated ionospheric conductivity. These two parameters may have quite different distributions in local time and latitude. For example, we find that in the cusp region where the local F-region ion concentration is high, the local joule heating rate is also

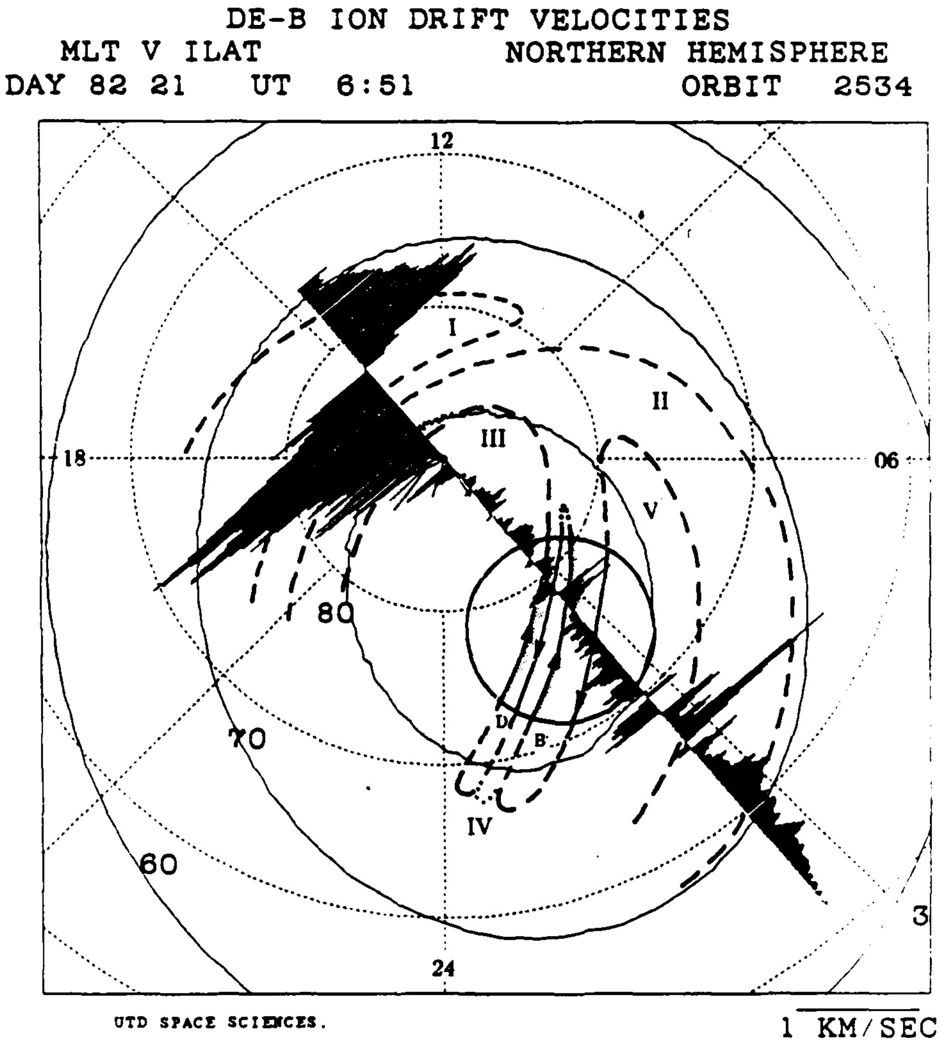

Figure 1. Schematic configuration of plasma flow associated with a sun-aligned arc

high due to the large electric field in this region. The heating rate per particle is however, quite low due to the large ion concentrations produced by low energy electron precipitation. The height integrated joule heating rate can be quite small in this region since the height integrated conductivity is fairly low and the ion velocities need not be much larger than those observed elsewhere in the auroral zone where the ionospheric conductivity is much larger. It is important to understand the differences between the local and height-integrated Joule heating rates and to undersatnd the influence of the neutral wind on our estimates of these parameters. Figure 2 shows the distribution of local joule heating observed by the DE-2 satellite [Heelis and Coley, 1988] An abstract describing more completely the findings of this study is included in this report.

High Latitude Plasma Structure

The characterization of plasma structure at high latitudes is important in determining both its effects on the propogation of radio signals and the processes for producing the structure. During this research period we have started an effort to allow easy access and visulization of ion concentration mesurements made from satellites This program includes the spectral analysis of selected data segments as well as high pass, low pass and band-pass filtering techniques. While the effort during this research period has been largely one of software development, we expect that big dividends will result for future research efforts. We plan to investigate the magnitude of the small scale plasma and electric field fluctuations that exist in the polar cap and in the auroral zones under different seasonal and IMF conditions.

Electrical Coupling in Structures

The presence of plasma structure in a confined altitude region of the ionosphere will induce structure to form elsewhere in regions connected by the Earth's magnetic field. This structure is produced by parallel diffusion of the original structure and by the mapping,

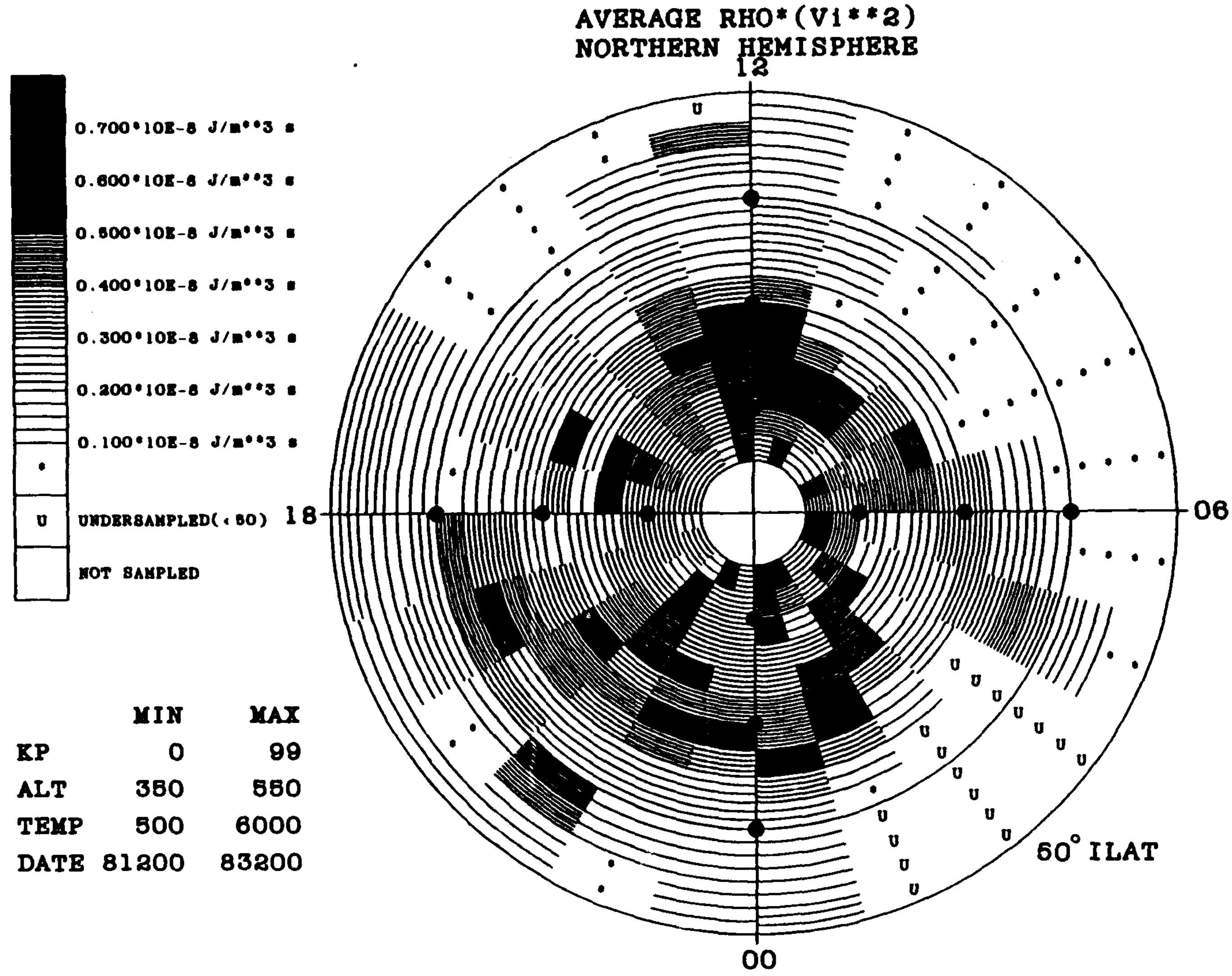

Figure 2. Spatial and Temporal distribution of local Joule heating rate derived from DE-2 data.

along magnetic field lines, of electric fields associated with the original structure. We have begun the development of computer code to decribe the details of the evolution of plasma structure that is subject to these processes. In previous work we treated the ionosphere as two conducting slabs between which electric fields of all scale-sizes mapped unattenuated. In the present formulation we have removed both these limitations and solved the equations of current and plasma continuity in two dimensions. Original investigation of the properties of electric field mapping reveal the very early results described by Farley [1959]. However, we have also investigated the role of the ionospheric plasma density profile on the mapping process. We find that the distribution of density in the bottomside F-region is critical to the details of the mapping process. This is illustrated in figure 3, where we show the potential distribution as a function of altitude for two profiles of the background ion concentration. It can be seen that the number densities change very little, but since they do so in a region where the ratio of the direct to the Pedersen conductivity changes rapidly, the mapping properties of the potential change quite radically. Thus the effects of F-region structure on the generation of structure in the bottomside F-region and E-region can be critically affected by the background ionization profile. We will pursue this property of the electric field mapping process in more detail in subsequent reports.

Analytic Convection Model

A series of simple analytical expressions to represent the two cell high latitude ionospheric convection pattern was developed by Heelis et al [1982] and used successfully in a number of large scale models of the ionospheric plasma and the neutral atmosphere dynamics and composition. Subsequent studies of ion drifts and electric fields exposed a significant drawback to the original formulation. It involved the use of symmetric geometric functions that forced the origin of the potential coordinate system to be the location of zero potential. This attribute of the convection pattern was shown to be violated by the many data sets that were examined. In response to this finding we have undertaken a different analytical formulation of the convection pattern and sought to define the dependences

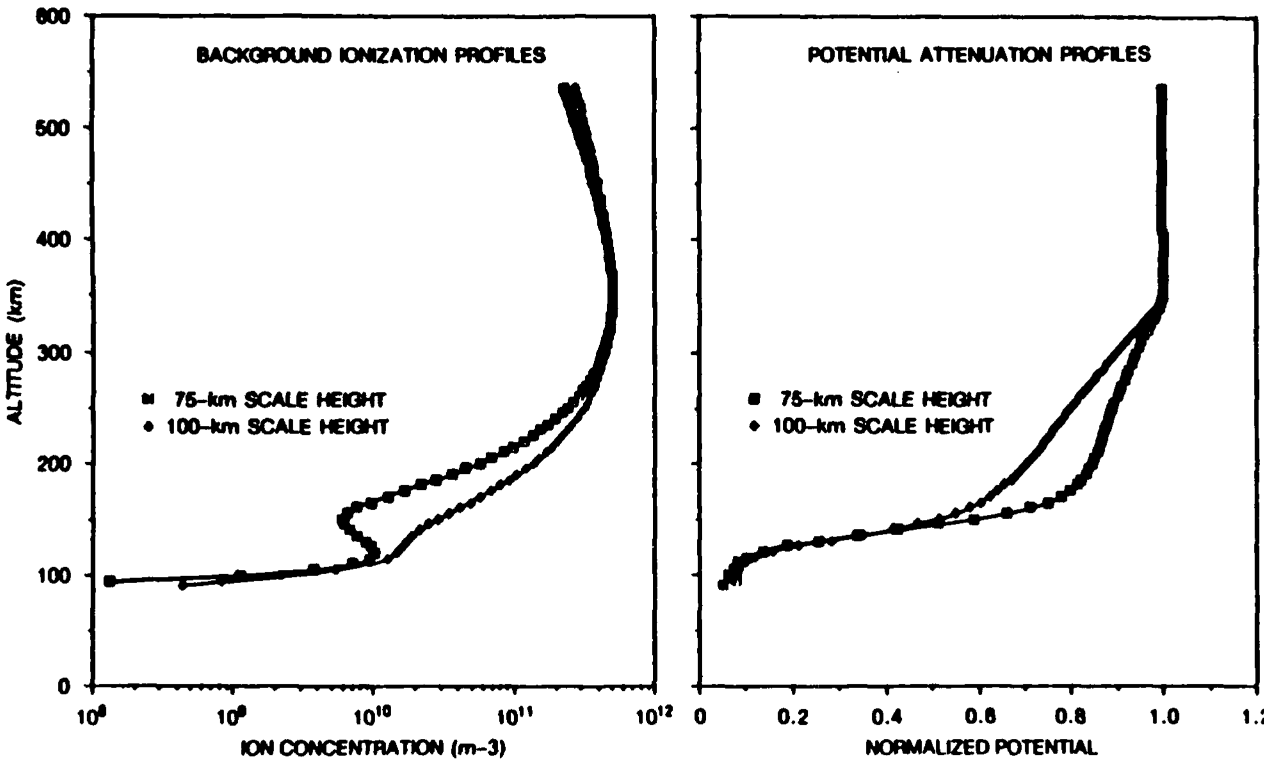

Figure 3. The attenuation properties of electric fields with 1 km scale-size are shown for differing ionospheric plasma distributions.

of the independent variables in the formulation on the IMF. The first attribute of the model must be the ability to produce asymmetric cell geometries that are dependent on the IMF. We have accomplished this by introducing the location of the zero potential inside the polar cap as a variable in the mathematical formulation. We then calculate spline functions that reproduce this location and the value of the maximum and minimum potentials specified on the convection reversal boundary. This technique has the advantage that the independent variables are easily specified by data from high inclination satellites. The functional dependences of these parameters on the IMF can then be easily obtained by utilizing these existing data bases and those that will become available from the DMSP satellites. Figure 4 shows the capability of the model formulation to produce asymmetric convection cells by varying the position of the zero potential inside the polar cap. Future work will be devoted toward developing the IMF dependences so that the model will function in ionospheric and themospheric codes by simply specifying the IMF.

Bulk Plasma Transport at High Latitudes

During periods of southward IMF all-sky images of the 6300 atmospheric emission imply the existence of patches of ionization that are enhanced with respect to the background by a factor of 4 or more, and that are convecting antisunward in the polar cap at the ExB drift speed. The processes by which temporal or spatial changes in the convection pattern could be responsible for these patches, has been examined during this research period. This research , in collaboration with scientists at AFGL, involves solving the continuity and momentum equations for the high latitude ionospheric plasma during it's convective path through the auroral zone and dayside cusp region. By varying the configuartion of the convection pattern, either in response to an implied change in the IMF Bz component or to a change in the By component, we are able to compare the observations at a fixed location with those expected if the convection pattern were unchanged. We can demonstrate that in the northern hemisphere, for periods when the IMF By component is positive, plasma in the morning side polar cap originates from the dusk side auroral zone

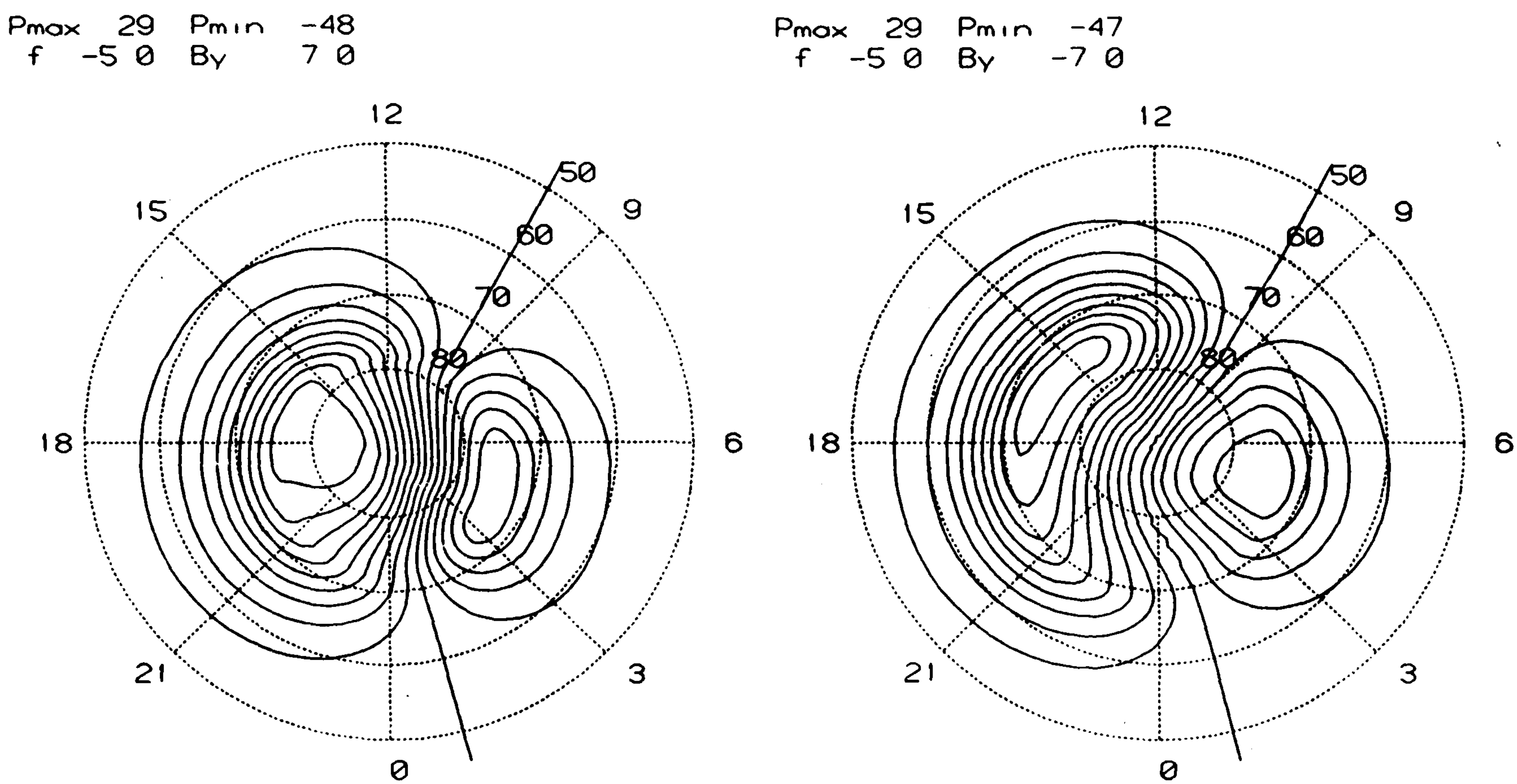

Figure 4. The analytic representation of the high latitude convection pattern for different configurations of the IMF.

and has a long convective path in sunlight before entering the dark polar cap. In contrast, when the IMF By is negative the plasma originates from the dawn side auroral zone and may have a very small or insignificant convective path in sunlight. The observed plasma densities inside in the polar cap for these two cases can easily vary by a factor of 6 or more. For a fixed orientation of the IMF given by the ratio By/Bz, similar changes in the polar cap plasma concentration can result from changes in the diameter of the polar cap associated with changes in Bz. Further investigations of this phenomena are now required to investigate the temporal variations in the convection pattern configuration that will produce the appropriate patch size observed at a fixed site.

APPENDIX

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COHERENT MESOSCALE CONVECTION PATTERNS DURING NORTHWARD INTERPLANETARY MAGNETIC FIELD

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Abstract. All-sky imaging photometer (ASIP) and coincident DE 2 satellite plasma drift and particle data have been combined to study polar ionospheric convection in the presence of subvisual intensity, soft-particle excited (F region), 6300-Å, Sun-aligned polar cap arcs. Coincident DE-B drift meter data identify these arcs electrodynamically as lines of negative electric field divergence. Based on conductivities, derived from the DE-B (low-altitude plasma instrument) measured particle fluxes, and the measured electric field gradients, the divergence of horizontal current across these particle impact excited arcs is in good quantitative agreement with upward Birkeland currents carried by the measured particle fluxes. Although velocity structure can be found without arcs, given the ASIP identified condition of stable weak (hundreds of rayleighs) 6300-Å Sun-aligned arcs in the polar cap, electric field negative divergence is consistently found. These arcs (of the order of 100 km in width) are found by ASIPs in the polar cap about half the time under $B_z > 0$ interplanetary magnetic field conditions. They are regularly seen by ASIP data to extend 1000 to over 2000 km in the sunward direction, and to persist in time often for over an hour. We are thus led to conclude that velocity gradients of this noon-midnight elongated scale are typical of $B_z > 0$ conditions. We further conclude that combined polar ASIP images and electrostatic potentials calculated along transpolar satellite tracks offer a valuable diagnostic for polar ionospheric convection studies under $B_z > 0$ conditions. The ASIP time continuous two dimensionality and the satellite equipotential scaling allow individual "snapshots" of these polar convection boundaries. Application here demonstrates highly anisotropic temporally stable convection with greater order than has previously been suspected.

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Global and Local Joule Heating Effects Seen by DE 2

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In the altitude region between 350 and 550 km, variations in the ion temperature principally reflect similar variations in the local frictional heating produced by a velocity difference between the ions and the neutrals. Here we show the distribution of the ion temperature in this altitude region and discuss its attributes in relation to previous work on local Joule heating rates. In addition to the ion temperature, instrumentation on the DE 2 satellite also provides a measure of the ion velocity vector representative of the total electric field. From this information we derive the local Joule heating rate. From an estimate of the height-integrated Pedersen conductivity it is also possible to estimate the global (height-integrated) Joule heating rate. Here we describe the differences and relationships between these various parameters.